THE DEVELOPED POROUS CONCRETE PAVEMENTS AND ITS PERFORMANCE

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ABSTRACT

Not to mention the increase of the widespread usage of porous asphalt, low-noise surface is considered as a promising technique from environmental points of view in Japan. But porous asphalts often show poor durability, especially in heavily traffic roads and in cold regions. Therefore, about 10years ago, a pavement quality porous concrete was developed and has been applied to several types of pavement structure.

The developed porous concrete has high total porosity in about 15-20%, and has as high flexural strength as dense concrete at around 4.5 MPa by adding of a special admixture. Using this material, full-depth type porous concrete pavements, whose thickness ranges 20-25cm, have been constructed for new roads on the trial basis. And thin bonded porous concrete overlays (inlays) have also been constructed in order to add high functions, like low-noise property and surface drainage, to the existing dense concrete pavements, even to the existing old porous concrete pavements. Most of these trials have been monitored continuously so far.

This paper describes their performances of this material as well as designs and construction techniques.

1. INTRODUCTION

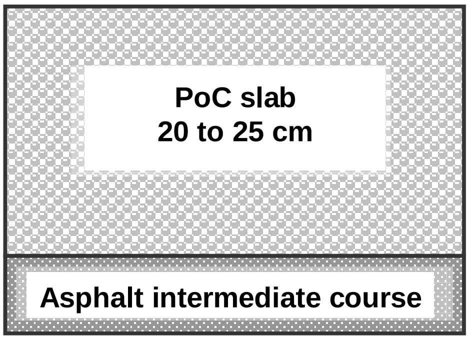
In order to create a safe and comfortable roadside environment, various environmental improvement technologies have recently been developed, including in the area of road paving. Various test constructions have been conducted to evaluate porous concrete pavement (hereinafter referred to as “PoCP”), an enhanced concrete paving method, with the aim of eventually applying this technology to an actual roadway. This method uses porous concrete (hereinafter referred to as “PoC”) with a porosity of as high as 15 to 20%. As a result of this, it offers benefits such as low noise properties, good drainage, and reduced temperatures in areas through which the paved roadway passes while providing the same level of durability as an ordinary concrete pavement. Thus, this paving technology is expected to improve both the vehicular travel environment and the roadside environment. A wide range of practical investigations (test constructions) have been performed to date to evaluate PoCP, including its application not only for new constructions but also for repair work, and in some cases the pavement has been in use for about a decade. In this paper, the authors first of all compile data from investigations conducted thus far on the current state of construction methods employed in PoCP, the properties of PoC, and the performance of PoC and then summarize what remains to be done for the future development of this method.

2. POCP CONSTRUCTION METHODS AND PROPERTIES OF POC

2-1. Investigated PoCP Construction Methods

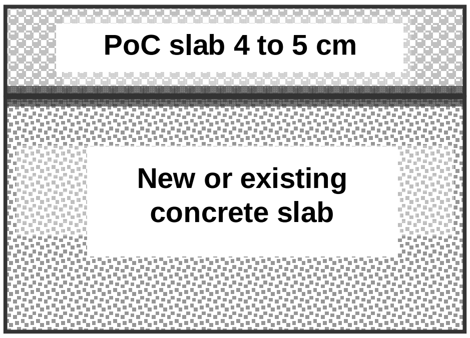
To date, two construction methods have been employed in investigating PoCP: the full-depth method and the thin-bonded method. In the full-depth method, PoC is used over the full depth of the pavement slab, while in the thin-bonded method, PoC with a thickness of 4 or 5 cm is bonded to and integrated with an ordinary concrete pavement slab to act as a functional layer on the slab. Figure 1 provides an outline of these two methods. For new construction work and reconstruction work such as repaving, the full-depth method shown in Figure 2 is applied.

<Outline of full-depth method>



- Asphalt intermediate course: 4 to 5 cm
- Joint spacing: 4 to 5 m
- Size of Aggregate in PoC: 5 or 13 mm

<Outline of thin-bonded method>



- Upper and lower surfaces at interface: bonding treatment
  (Lower surface treatment + binder)
- Joint spacing: same as that for lower concrete
- Size of Aggregate in PoC: 5 or 13 mm

Figure 1. Outline of investigated PoCP methods

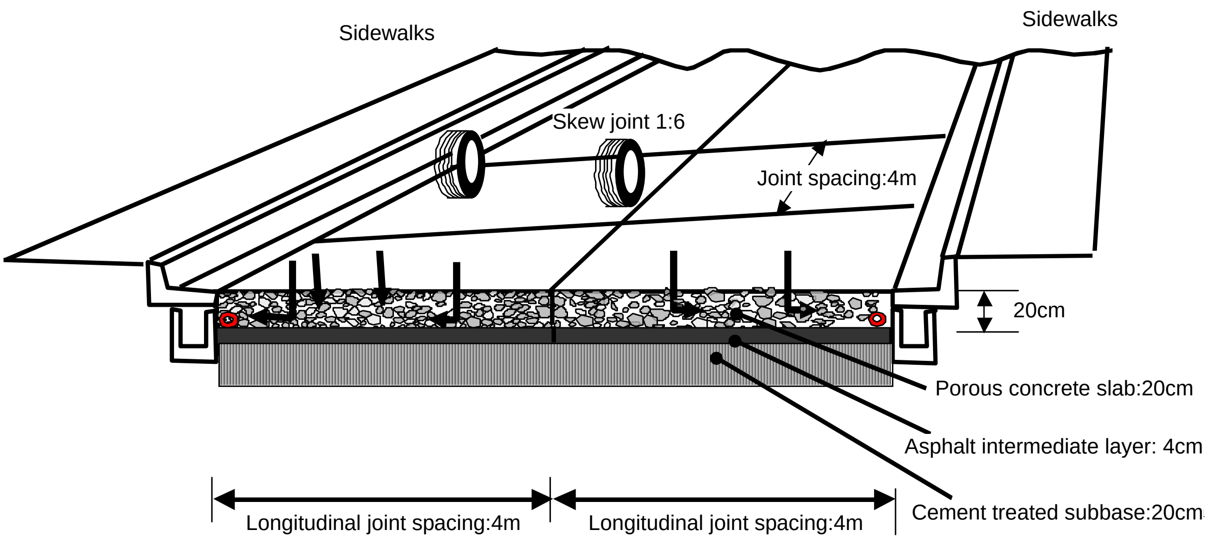


Figure 2. Typical full-depth porous concrete pavement

For repair work that is subject to economic and formational constraints and when fast construction work is required, the existing concrete pavement slab is cut away to a prescribed depth and the area overlaid with PoC using the thin-bonded method, enabling the applicability of this method to be investigated. The thin-bonded method is also applied in concrete-paved areas around newly constructed tollgates to provide additional oil resistance and drainage. With both methods employed in PoCP construction, an asphalt finisher (AF) is used for spreading and compaction and a small, rubber-wrapped roller is used for rolling and finishing. The procedures employed in PoCP construction are shown in Figure 3, and an example of PoCP construction is shown in Photograph 1.

<Construction flow for full-depth method>

- Construction of subbase
  - Asphalt intermediate course
- Preparatory work
  - Form placement and other such work
- Fabrication and transportation of PoC
  - Dump truck
- Spreading and compaction
  - Asphalt finisher used for high compaction
- Surface finishing
  - Small, rubber-wrapped roller used
- Joint work
  - Construction of preformed joints during pavement construction
  - Construction of cut joints
- Curing
  - Plastic sheet or the like

<Construction flow for thin-bonded method>

- Surface treatment of lower layer
  - Shot blasting or the like
- Bond coating
  - Special cement mortar or the like
- Fabrication and transportation of PoC
  - Agitator truck
- Spreading and compaction
  - High compaction asphalt finisher used
- Surface finishing
  - Small, rubber-wrapped roller used
- (Joint work)
  - Construction of joints in alignment with lower concrete
- Curing
  - Plastic sheet or the like

Figure 3. PoCP construction procedures

Photograph 1. Example of PoCP construction (full-depth method)

2-2. Mix of PoC

The PoCP constructed to date was required to have roughly the same durability as ordinary concrete pavement while having a porosity of about 15 to 20%. Thus, the mix design is performed to attain the target values set as shown in Table 1.

Table 1. Target properties of PoC

Item	Target value
Porosity	15 to 20%
Bending strength	4.5 MPa
Coefficient of permeability	10^{-2} cm/sec and more

The raw materials that make up PoC include water (W), cement (C), a special inorganic additive (RM), fine sand (S), and crushed stone (G) of up to 5 m or between 10 and 13 mm in size. An example PoC mix is shown in Table 2.

Table 2. Mix example of PoC

Construction method	P/S (%)	W/P (%)	m/g (%)	Porosity (%)	Unit content (kg/m³)				
					W	C	RM	S	G
Full-depth	2.0	18	48	18	68	324	56	190	1457
Thin-bonded	2.0	22	48	18	81	304	56	179	1507

Remarks:
P (binder) = C+RMS; P/S = ratio of binding agent to coarse aggregate mass; W/P = ratio of water to binding agent; m/g = ratio of mortar to coarse aggregate

Due to the addition of a special additive, the mortar in this PoC has a very low unit water content so it is viscous and firm. The coarse aggregate is wrapped in this mortar, and this structure results in a large amount of coarse aggregate being bonded.

2-3. Properties of PoC

(1) Strength characteristics

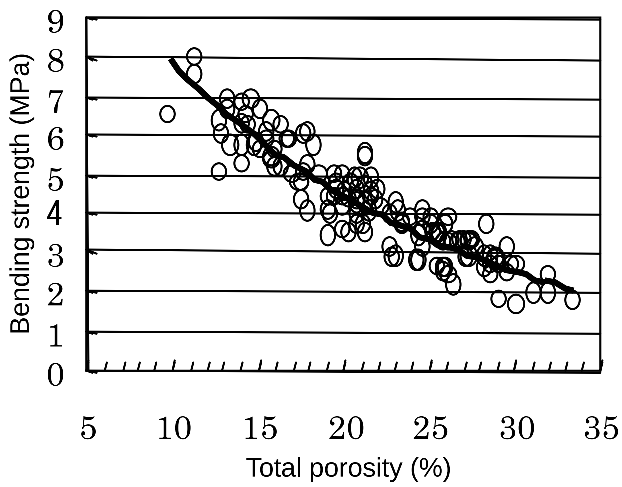


Figure 4. Bending strength in relation to porosity for PoC

The strength of the PoC used is governed by its porosity, and the maximum porosity for which a bending strength equivalent to that of paving concrete (σ b28 = 4.5 MPa) can be ensured is about 20% (Figure 4[1]).

(2) Modulus of elasticity and thermal expansion coefficient

According to measurements of the modulus of elasticity and thermal expansion coefficient for PoC (Table 3[2]), PoC's modulus of elasticity decreases as its porosity increases and tends to be smaller than that of ordinary paving concrete (30 to 35 GPa). Its thermal expansion coefficient is about the same as that of ordinary concrete (about 10 $\times$ 10^{-6}/°C).

Table 3. Modulus of elasticity and linear expansion coefficient for PoC

Porosity (%)	Modulus of elasticity (GPa)	Thermal expansion coefficient ($\times 10^{-6}$/°C)
15	24.5	9.0
20	25.5	8.5
25	18.6	8.3

(3) Fretting resistance of the aggregate

The results of the Cantabro test conducted on PoC are shown in Figure 5[2]. The fretting resistance of the aggregate is correlated with porosity, and the amount of aggregate loss for porosities of 15 to 20% is 10 to 15% in general.

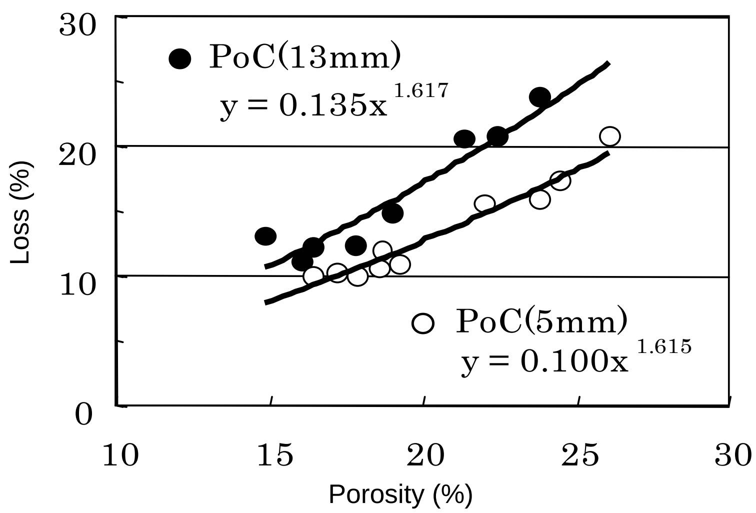


Figure 5. Results of the Cantabro test for PoC[1]

3. OUTLINE AND CURRENT STATE OF CONSTRUCTIONS FOR WHICH THE POCP METHOD WAS EMPLOYED

3-1. Full-depth Method

An outline of constructions to date for which the full-depth method has been employed is shown in Table 4 and their current performance is presented in Table 5. Photograph 2 and Photograph 3 shows the current state of a section of roadway constructed using the PoCP method that went into service 7.5 and 9.5 years ago.

Table 4. Outline of constructions for which the full-depth method was employed

Construction site	Size of aggregate	Cement used	Area (m^2)	Construction date	Pavement structure
A	13 mm	ordinary Portland cement	700	Nov. 1999	PoCP: 20 cm As intermediate course: 4 cm Granular subbase: 20 mm
B	10 mm		700	Nov. 1999	
C	10 mm		800	Nov. 1999	
D	13 mm 5 mm		800 (@400)	Nov. 1999	PoCP: 20 cm As intermediate course: 4 cm Cement treatment: 20 mm
E	5 mm	Eco-cement	700	Dec. 2001	PoCP: 20 cm As intermediate course: 4 cm Cement treatment: 20 mm

Table 5. Serviceability of full-depth method

Construction site	Length of investigation	Size of aggregate	Cracking	Noise reduction*	Permeability**
A	For 5 years after service began	13 mm	None	1 dB	—
B		10 mm	None	1 dB	—
C		10 mm	At corners on some slabs	1 dB	—
D	For 7.5 years after service began	13 mm	Longitudinal cracking on some slabs	0 dB	25
		5 mm	Transverse cracking on some slabs	2 dB	20
E	For 5 years after service began	5 mm	Transverse cracking on some slabs	2 dB	20
Remarks	*: Noise reduction in comparison with adjacent ordinary asphalt pavement **: The permeability given is the proportion to the value of an adjacent reference construction section of permeable pavement taken to be 100.				

Photograph 2. Site E of roadway constructed using the full-depth method that went into service 7.5 years ago

Photograph 3. Site C of roadway constructed using the full-depth method that went into service 9.5 years ago

This construction method came into use 7 to 9.5 years ago and the current performance of roads constructed using this method can be summarized as follows:

- Longitudinal cracking, which could conceivably be due to material segregation, has occurred in places; however, the surface texture is generally good.
- Although no dowel bars were installed, this has not resulted in steps or other defects.
- The joint spacing was taken to be 4 or 5 m; however, a joint spacing on the Asphalt intermediate course of about 20 times the slab thickness is conceivably appropriate for the full-depth method because no transverse cracking has occurred.
- Even 5 to 8 years after these pavements entered service, a noise reduction of 0 to 1 db greater than that of ordinary asphalt pavements was confirmed in a road section with a Size of aggregate of 10 to 13 mm, and about 2 db was confirmed for a section of 5 mm.
- The drainage of these pavements has degraded further than that of adjacent porous pavements.
- On a road to which this method was applied that is located in a cold, snowy area, no evidence has been found of rutting due to abrasion, aggregate fretting, or other significant damage.

3-2. Thin-bonded Method

For the thin-bonded method, our study was conducted mainly to evaluate the functional enhancement of concrete paving around tollgates, both for new constructions and repairs. Pavements constructed using this method were put into service about 8 to 9.5 years ago, and an outline of their construction and current performance are summarized in Table 6. For repair work, a PoC that strengthens and hardens rapidly has been developed and is now being applied.[3)]

Site G(new) of roadway constructed using the thin-bonded method that went into service 9.5 years ago is shown in Photograph 4.This is no sign of cracks or other such damage. The surface texture is generally good.

A degradation of drainage properties has been seen at and around vehicle stop points; however, there is no sign of surface PoCP spalling, the formation of potholes, and other such damage. At construction site M (repair) in particular, there is no sign of cracks or other such damage and good performance has been maintained despite it being located on a route that carries heavy traffic (Photograph 5).

Table 6. Outline and current state of thin-bonded method

<table>
<tr><th>Construction site</th><th>Size of aggregate</th><th>New construction or repair</th><th>Area (m^2)</th><th>Construction date</th><th>Pavement structure*</th><th>performance and functionality</th></tr>
<tr><td>F</td><td>10 mm</td><td rowspan="7">New construction</td><td>1,700</td><td>Oct. 1999</td><td>PoCP: 5 cm
CRCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>G</td><td>10 mm</td><td>1,200</td><td>Oct. 1999</td><td>PoCP: 4 cm
CRCP: 25 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>H</td><td>10 mm</td><td>1,100</td><td>Feb. 2000</td><td>PoCP: 5 cm
JCP: 25 cm</td><td>Defective bond with lower layer in places
Permeability degraded around vehicle stop points</td></tr>
<tr><td>I</td><td>13 mm</td><td>1,400</td><td>Jun. 2000</td><td>PoCP: 5 cm
CRCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>J</td><td>10 mm</td><td>1,200</td><td>Aug. 2000</td><td>PoCP: 5 cm
CRCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>K</td><td>10 mm</td><td>1,200</td><td>Dec. 2000</td><td>PoCP: 5 cm
CRCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>L</td><td>10 mm</td><td>1,300</td><td>Feb. 2001</td><td>PoCP: 5 cm
CRCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>M**</td><td>13 mm</td><td>Repair</td><td>1,100</td><td>Feb. 2001</td><td>PoCP: 5 cm
JCP: 20 cm</td><td>No structural problems
Permeability degraded around vehicle stop points</td></tr>
<tr><td>Remarks</td><td colspan="6">* Pavement structure: (upper layer = PoCP) + (lower layer = pavement concrete slab)
(PoCP = porous concrete pavement slab; JCP = jointed concrete pavement slab; CRCP = continuously reinforced concrete pavement slab)
** Construction site M: JCP (25 cm) cut to 5-cm depth + PoCP (5 cm) overlay</td></tr>
</table>

Photograph 4. Site G of roadway constructed using the thin-bonded method that went into service 9.5 years ago

Photograph 5. Site M of roadway constructed using the thin-bonded method that went into service 8 years ago

4. SUMMARY AND FUTURE TASKS

The current performance and functionality of the PoCP method and actions that need to be taken based on these factors can be summarized as follows:

- With regard to the full-depth method, cracks can be seen in places; however, the current performance is generally good. It can be assumed that the structure, material, and construction method for PoCP have, for the most part, been established.
- With regard to the full-depth method, the pavement structure and construction methods are being investigated with a view to applying this method to routes that carry heavy traffic and this presents an ongoing challenge.
- A noise level of 3 to 7 db lower than that of ordinary asphalt pavements was confirmed for pavements constructed using the PoCP method immediately after construction and of 0 to 2 dB 5 to 8 years after these pavements entered service. Going forward, a future challenge will be establishing a means of maintaining or restoring this level of noise reduction.
- The permeability of pavements constructed using the PoCP tends to degrade. Consequently, a more porous PoC and a means of restoring the porosity of the PoC will need to be developed.
- Because of the development of an early-opening-to-traffic PoC, the thin-bonded method can be applied to concrete pavements, including those on routes with heavy traffic, to functionally enhance or repair them.
- Going forward, a future challenge will be the application of the PoCP method to repairing existing asphalt pavements (the white topping method).

5. CONCLUSION

The road sections constructed using the PoCP method that we have investigated remain in service 7 to 9.5 years after their construction. Although cracking can be seen in some sections, no steps or potholes have formed and there is no other noticeable damage so they can be described as being in generally good condition. Thus, the PoCP method can conceivably be applied as a durable concrete pavement. With the development of early-opening-to-traffic porous concrete, PoCP can be deployed widely from new construction to repair work and it is expected to be used in the white topping method with a view to its application in asphalt pavement repair work. Going forward, we will continue our performance investigation to clarify the applicability of PoCP. At the same time, we intend to conduct a

study on labor saving and cost reductions in construction work to contribute to further spreading the use of the PoCP method.

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3. Nakahara et al. Study on Practical Application of an Early-Opening-to-Traffic Porous Concrete Pavement, Hoso, pp. 9–14 (Sept. 2002)